THE ELECTRICAL PULSE DUPLICATOR—ITS USE IN TESTING VALVE PROSTHESES WITH SPECIAL REFERENCE TO THE AORTIC AND MITRAL VALVES

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Progress in modern open heart surgery and the use of cardioplegic drugs,[1-3] retrograde perfusion of the coronary sinus,[4] or other means of supporting the myocardium during cross-clamping of the ascending aorta, has made direct surgery on any of the four valves of the heart possible. At present there appears to be general agreement that the ideal correction of acquired valvular defects awaits the development of suitable prosthetic valves.

Before a prosthesis of any design can be used for the correction of a valvular defect in patients it should fulfil the following criteria:

(*a*) The prosthesis should be of such design that it can be inserted and secured in the limited space that exists in the annulus of the valve to be corrected.

(*b*) It should function freely under the conditions which exist at that particular point of the circulation and continue to function for many years.

(*c*) It should be tolerated within the circulation; that is to say, it should not be extruded as a foreign body.

(*d*) It should not damage the elements of the blood or the heart itself, or promote clotting of the blood with embolization.

Part of the work in testing fabricated prosthetic valves thus necessitates the study of valvular mechanics by dynamic demonstration of the action of these valves. If this is done under hydrodynamic conditions, similar to those present during life, such an investigation will determine whether the valve being tested will function freely and adequately when used for the correction of valvular insufficiency. By leaving the prosthetic valve to function under these conditions for long periods of time at speeds of 120-150 cycles per minute, fatigue can be studied, giving useful information on how the valve will withstand the systolic and diastolic forces throughout life.

The purpose of this paper is to describe a method by which prostheses for the correction of regurgitant aortic and mitral valves can be tested in a pulse duplicator to determine whether they fulfil some of the criteria listed above.

APPARATUS

The Electrical Pulse Duplicator

The important part of an apparatus used in testing prosthetic valves for the left side of the heart is a pulse duplicator capable of producing a pulsatile flow of fluid comparable in volume and pressure to the stroke of the left ventricle. An electrical pulse duplicator used by us for this purpose is illustrated in Fig. 1. This apparatus consists of a T-tube A, 1 inch in diameter. One limb of this tube is connected through a solenoid valve B, 1 inch in diameter, to a water tap. Water was found to be the most satisfactory

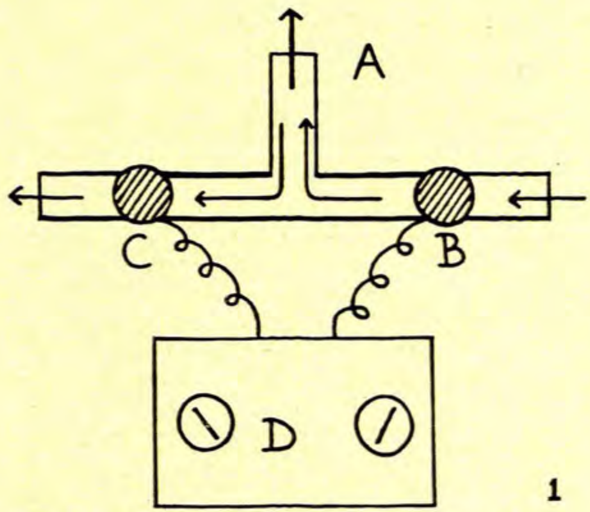

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Fig. 1. Diagram of the electrical pulse-duplicator.

perfusion fluid for photographic purposes, and the water pressure in the tap provides inexpensive power for the pulsator. The second limb leads off to a drain through a second solenoid valve C, of similar diameter.

The two solenoid valves are electrically activated. The rate, and systole-diastole ratio corresponding to different rates, are controlled by two switches on control box D. This control system is constructed in such a manner that the one solenoid valve is open while the other is shut and *vice versa.* The third limb of the metal tube is connected to the testing chamber, which varies with each valve to be tested and the type of test done.

Testing Chambers for Aortic-valve Prostheses

In order to test an aortic-valve prosthesis, the duplicator is connected to two chambers, A and B, manufactured from quarter-inch-thick plexiglass (Fig. 2). These two chambers are separated by a disc C, in which the valve to be tested is inserted. It is possible to unscrew chamber A from chamber B, and also to unscrew the lid of chamber B, thus allowing insertion of the valve and operation on the valve once it is in position.

In order to observe whether the valve to be tested can be secured in the root of the aorta and whether it will function freely, the base of the aorta together with the aortic valve and half an inch of ventricular muscle and the aortic leaflet of the mitral valve are excised from a post-mortem human heart (preferably from a patient who died of aortic regurgitation) and attached between two strips of Ivalon as shown in Fig. 3A. When the purpose of the test is to see how long the prosthesis will last when subjected to forces similar

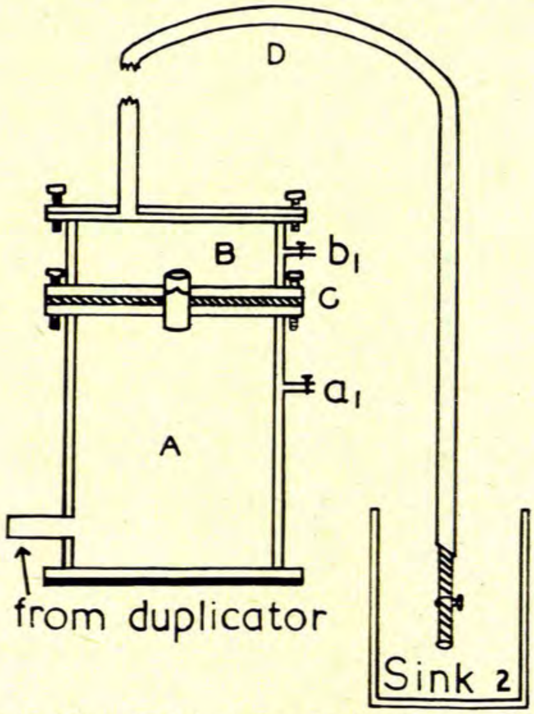

Fig. 2. Diagram of the testing chamber for studying the aortic valve.

to those in the circulation, it is set up as shown in Fig. 3B attached to a strip of Ivalon overlying an opening approximately the size and shape of the aortic valve in mid-cycle.

After the chambers have been screwed together with a valve in position the only connection between them is through the valve.

An inverted plastic U-tube D, 1 inch in diameter, is attached to the top chamber (Fig. 2). The length of the ascending limb of this tube can be adjusted so that, when filled with water, the desired pressure is exerted on the valve. The descending limb is connected by way of a compressible rubber tube to the water drain. The pressure in this tube can thus be adjusted further by partially clamping the rubber tube. This, in conjunction with the air trapped in the descending limb, will allow of elastic resistance simulating the peripheral resistance in the human circulation.

Testing Chambers for Mitral-valve Prostheses

When testing a mitral-valve prosthesis for strength and durability, the assembly is the same as for the aortic valve except that chamber A now has an outlet which leads to the drain (the aortic outflow) and chamber B, instead of the inverted U tube, has an adjustable water supply (pulmonary veins supplying left atrium)—Fig. 4A. The valve to be

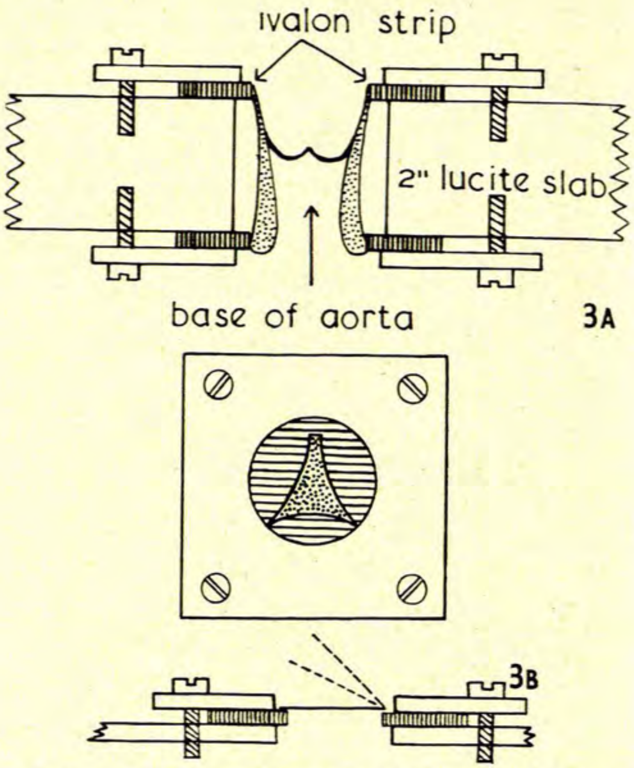

Fig. 3. Diagram showing the method of fixation of the aortic valve in the testing chamber: (A) For studying valve action. (B) For studying durability of the valve.

tested is secured in the manner described above in a piece of Ivalon. In order to see whether the prosthesis can be secured in the mitral annulus and whether it will function freely, the apparatus is set up as shown in Fig. 4B. A fresh human heart is removed at post-mortem (preferably from a patient who died of mitral regurgitation). The roof of the left auricle is excised below the entrance of the pulmonary veins. The left auricular appendage is ligated at its base and a linen purse-string suture is placed around the circum-

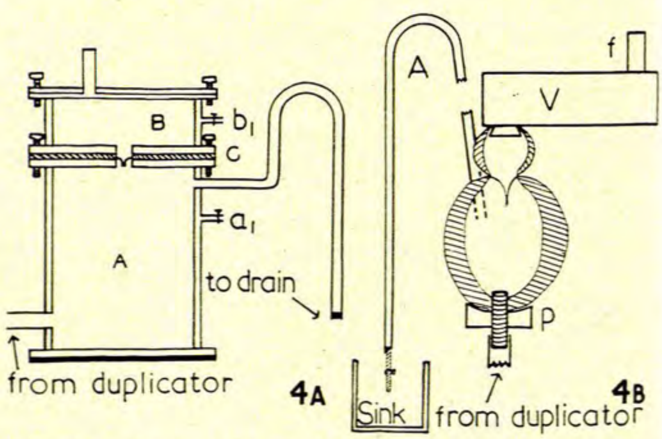

Fig. 4A. Diagram of testing chamber as used for the study of the durability of a mitral prosthesis.
Fig. 4B. Diagram showing the apparatus used for the study of the mitral valve.

ference of the auricular defect, through which the plexiglass viewing chamber V is attached. The roof of the aorta is dissected free from the pulmonary artery and the vessel is transected approximately 2 inches from its origin. A purse-string suture is placed about its circumference just proximal to the line of transection, to which the ascending limb of an inverted plastic U-tube A is attached.

The apex of the left ventricle is amputated so as to afford entry to the ventricular cavity and a thick linen purse-string suture is placed around this opening. A metal tube which passes through a cylindrical plexiglass block P is screwed through the hole in the apex into the left ventricular cavity and secured in position by tying the purse-string. The heart rests on the cup-shaped upper surface of the plexiglass block; the other end of the metal tube is connected to the duplicator. The heart and tubes attached are supported by suitable stands. The test can now be started. By unscrewing the lid of the viewing chamber V, the valve to be tested can be secured in the annulus of the heart.

METHOD OF TESTING VALVES

Aortic valve. The testing chambers and valve to be tested are set up as described above and connected to the pulse duplicator. Inlet valve B, is opened, the water tap turned on,

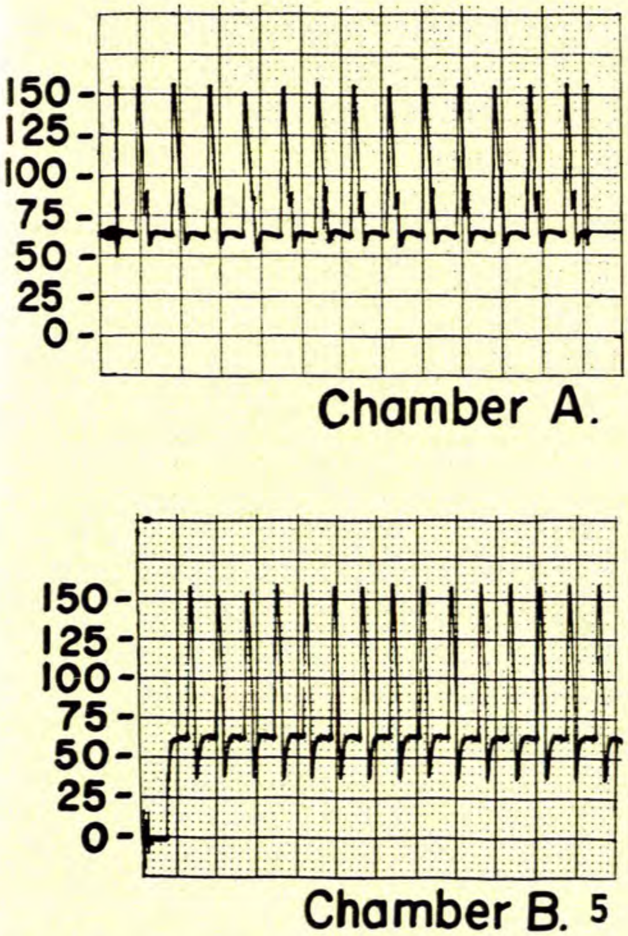

Fig. 5. Pressure tracings recorded while studying a competent aortic valve.

and the system filled with water, expelling all the air. When this is complete the control box is switched on and the speed and systole-diastole ratio adjusted to give the desired rhythm of pulsation. The pressure changes in the two chambers (left ventricle and aorta) are measured by connecting taps a_1 and b_1 to a pressure-recording device. By adjusting the

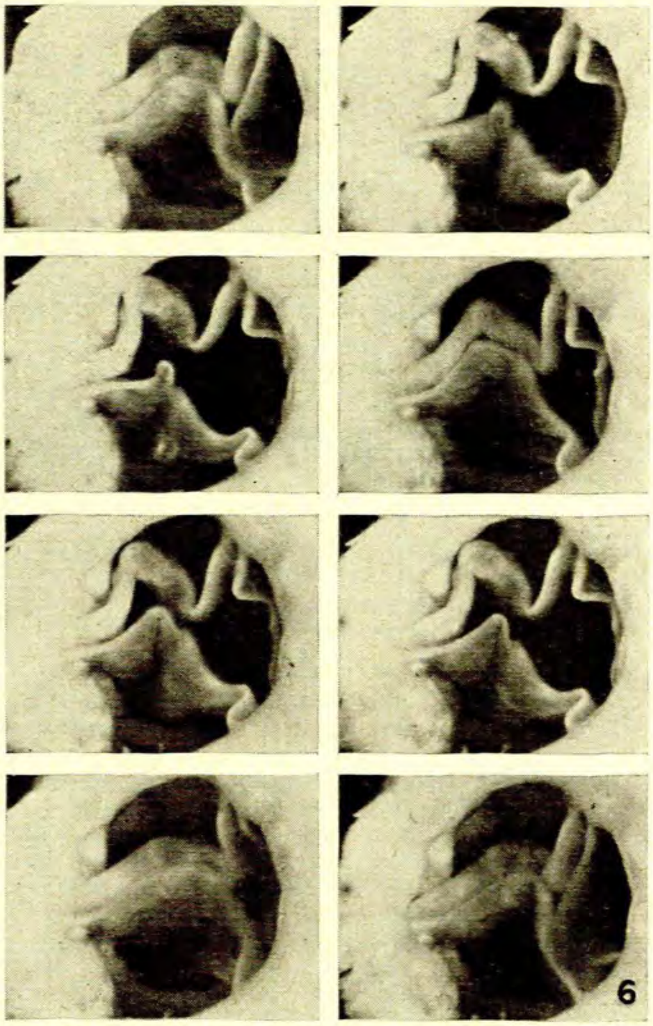

Fig. 6. Cycle of normal aortic-valve movements showing the opening and subsequent closure.

water inflow, the height of the ascending limb of the inverted U-tube, and the resistance in the descending limbs, the output per minute and pressure changes closely simulating those in the human circulation can be obtained (Fig. 5). The action of the valve can be observed and photographed through the top of chamber B (Fig. 6).

Mitral valve. The testing chambers are connected as described and connected to the pulse duplicator. The system is filled with water as for the aortic valve, systole and diastole adjusted, and pressures recorded in the top and bottom chambers (left auricle and left ventricle). The diastolic loss of fluid from the viewing chamber into the ventricles is compensated for, by the constant addition of water *via* the water supply f (Fig. 4B). It is essential to maintain the fluid level in this chamber during photography of the valve in

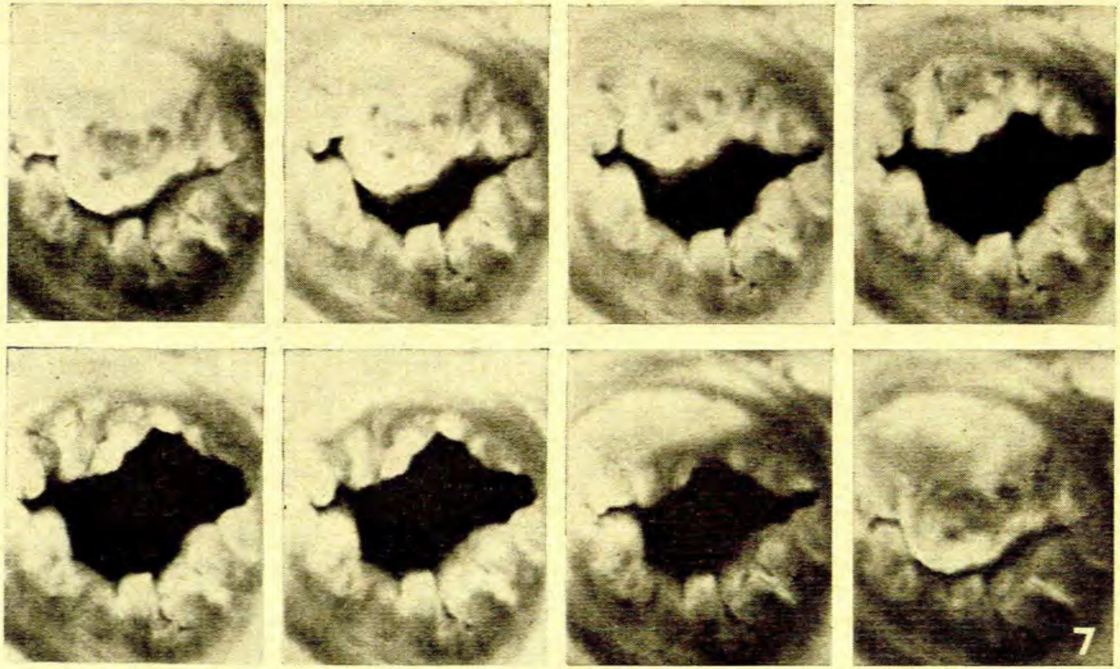

Fig. 7. Cycle of normal mitral-valve movements showing the opening and subsequent closure.

order to avoid the presence of bubbles or a receding water meniscus, which may impair visibility. The action of the valve can be carefully observed and photographed through the top chamber (Fig. 7).

CONCLUSION

The use of the artificial pulse duplicator makes it possible to study the action of normal and abnormal aortic and mitral valves under conditions of pressure and flow similar to those present in the beating heart. Intrinsic valvular action, however, cannot be evaluated in such a system, but despite these disadvantages the apparatus has proved to be of great value for the study of the action of prostheses designed to correct incompetent valves, and, in addition, such a system may be used to test the durability of a prosthesis under conditions similar to those found during life.

SUMMARY

The construction and method of operation of a simple inexpensive artificial pulse duplicator is described. Such a system enables one to study and photograph the action of normal and abnormal valves and also to study and test prosthetic valves under conditions of pressure and volume flow similar to those existing in the normal circulation.

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